

VWC3

020592000096246


R0705Q7000006246B

Master Copy

*J. D. Walecka
Continuous Electron Beam Accelerator Facility
12070 Jefferson Avenue
Newport News, VA 23606*

Panic '87 Conference
XI International Conference on Particles & Nuclei
Kyoto, April 20-24, 1987

J. D. Walecka
The Continuous Electron Beam Accelerator Facility
Newport News, Virginia

Summary Session

First I would like to thank the hosts for all their hard work in making this conference a success and for giving me a chance to revisit the lovely city of Kyoto. I was sitting with Torleif Ericson at the banquet last night and we were trying to count how many of the participants here were at the 1963 conference at CERN; we got to six. I was one of them, so that means that now I am a senior citizen and I can pontificate and talk in generalities, which is exactly what I am going to do. I am not going to give a technical talk. You have had a week of technical talks; you do not need another one. And I am also going to concentrate on nuclear physics.

Let me go back to the beginning. Why do we do nuclear physics? Why is nuclear physics interesting? First, the nucleus is a unique form of matter. It consists of many baryons in close proximity. Second, all the forces of nature are present in the nucleus - strong, electromagnetic and weak. The nucleus provides a unique microscopic laboratory to test the structure of the fundamental interactions. Furthermore, the nuclear many-body problem is of intrinsic intellectual interest. Most of the mass and energy in the visible universe comes from nuclei and nuclear reactions. Finally, to me, nuclear physics is really the study of the structure of matter.

I am also going to talk primarily about electromagnetic interactions, in particular, electron scattering [1]. Why do we do electron scattering? Why is electron scattering interesting? First, the interaction is known. It is given basically by quantum electrodynamics (QED), which is the most accurate physical theory we have. Second, the electron provides a clean probe; we know what we measure. We measure the electromagnetic current density in the target. The interaction is relatively weak, of order of the fine structure constant α , so we can make measurements on the target without greatly disturbing its structure. What we basically measure in electron scattering is a diffraction pattern. We have a set of spectrometers in the laboratory, and we measure a diffraction pattern. Now I will just give you an example in Figure 1. This is the diffraction pattern we see when we scatter elastically from the ^{40}Ca nucleus [2]. Notice the scale here. It is logarithmic and extends over 13 decades. That diffraction pattern is essentially the Fourier transform of the ground-state charge density; or more generally, of the ground-state charge and current densities. By inverting that Fourier transform, we have a measurement of the spatial distribution of these quantities in the nucleus. Here in Figure 2 is the charge distribution in ^{40}Ca deduced from that diffraction pattern. The charge density is a function of the radius in Fermis. The little hatched area gives you an idea of our present experimental uncertainty in the ^{40}Ca charge distribution. I remind you that it is a basic property of the Fourier transform that the distance scale probed bears an inverse relation to the momentum transfer.

Furthermore, electrons are a versatile nuclear probe because not only is there an interaction with the charge density, there is an interaction with the convection current, the current arising because of the flow of the charge. And you know that nucleons are little magnets; they give rise to an intrinsic magnetization in the target. The curl of that magnetization gives rise to an additional current that we can probe with electrons.

Let me say a little bit about how we do nuclear physics. The traditional approach starts from static two-body potentials fit to two-nucleon scattering data. You insert these potentials into the non-relativistic many-particle Schrödinger equation, and then you solve that equation within some approximation [3], or in the two- and three- body problem, you can now essentially solve those equations exactly. You construct the nuclear currents from the properties of free nucleons, and you use these currents to probe the system. Now although this traditional approach to nuclear physics has had a great many successes, it is clearly inadequate for a more detailed understanding of the nuclear system.

A more appropriate set of degrees of freedom consists of the hadrons - the strongly interacting mesons and baryons. For example, the long-range part of the Paris potential, probably the most accurate currently available, consists of the exchange of mesons: pions, sigma, rhos, omega, and so on. Also, one of the major achievements in this field in the last half-dozen years is the unambiguous identification of exchange currents in nuclei. These are additional currents present in the nuclear system arising from the flow of charged mesons between the baryons.

Furthermore, a current goal of nuclear physics is to study the property of nuclear matter under extreme conditions. We want to know what happens at high temperature and at high pressure, for applications to astrophysics and to relativistic heavy-ion reactions. We also want to know the response of the nuclear system to a high-momentum-transfer probe.

In order to obtain a theoretical description of the nuclear system under these conditions, it is essential to incorporate general principles of physics in our description, such as quantum mechanics, special relativity, and causality. The only consistent theoretical framework we have for such an interacting relativistic many-particle system is relativistic quantum field theory based on a local lagrangian density. I like to refer to such relativistic quantum field theories of the nuclear system based on hadronic degrees of freedom as quantum hadrodynamics or QHD [4].

Certainly one of the great intellectual achievements of our era has been the unification of the theories of the electromagnetic and weak interactions [5-7]. It is essential to continue to put this standard model of the electroweak interactions to rigorous tests. Furthermore, we now have a theory of the strong interactions binding quarks into the observed hadrons. It is based on an internal color symmetry and the theory is quantum chromodynamics or QCD [8]. We thus have a standard model of the strong, electromagnetic, and weak interactions which is a local gauge theory based on the underlying symmetry structure $SU(3)_c \otimes SU(2)_w \otimes U(1)_y$. In this talk I would like to say a little bit about how we can use electroweak interactions to probe the structure of this standard model of the strong, electromagnetic, and weak interactions, and furthermore, how we can use nuclei to study the structure of the strong interactions.

Let me just say a couple of words about QCD, and remind you of two of its properties [8]. The first property is asymptotic freedom. Roughly speaking, asymptotic freedom says the following: when all the momenta entering into a process are very large, or equivalently at very short distances, the renormalized coupling constant governing that process goes to zero. That means one can do perturbation theory in this regime. The other property is confinement. The underlying set of degrees of freedom in the theory, the quarks and the gluons, are never seen as free asymptotic scattering states in the laboratory. There are strong indications from lattice gauge theory calculations, as we have heard about at this conference, that confinement is indeed a dynamical property of QCD coming from the nonlinear gluon interactions in the theory.

I will give you one example of the relativistic aspects of nuclear structure. I want to talk about elastic magnetic electron scattering from ${}^3\text{He}$, and I want to take you through a very simple calculation. The simplest model of ${}^3\text{He}$ is a $(1s_{1/2})^{-1}$ neutron hole in the alpha particle. If we use oscillator wave functions, we can fit the oscillator parameter to elastic charge scattering from this system and you can then all calculate the magnetic form factor of ${}^3\text{He}$; you get the solid curve in Figure 3. Now I will add in the pion exchange current. As I have said, this is the current arising because of the flow of charged mesons between two nucleons. And in fact it turns out that I can calculate the long-range part of this exchange current exactly from low-energy theorems. I know its form precisely at large internucleon separation. This was first pointed out, I believe, by Prof. Miyazawa. If I add in this pion exchange current, I get the dashed curve in Figure 3. Also shown is some of the early Stanford low- q^2 data. Now you simply are not going to make much money from this comparison, right? But now let us suppose that we have the capability and the facility to go to high momentum transfer and do the same experiment [10]. In Figure 4 is essentially the same low- q^2 data I showed before, together with intermediate- and high- q^2 data from Bates and Saclay. It is divided by q^2 so that it comes up to one at low- q^2 . The dashed curve is the result you get from solving the Faddeev equations for this three-body system, assuming structureless nucleons. The solid curve is what you get when you add in the pion exchange current. As I have said, at large distance, or at low q^2 , you can essentially make an absolute calculation of this pion exchange current contribution. And whereas at low q^2 it is a small effect, by the time one gets to high q^2 , the pion exchange current dominates by several orders of magnitude. It is clearly required at intermediate and high q^2 in order to describe the data.

I would like to draw some conclusions from this comparison. The first one is that the intermediate momentum transfer results illustrate the marginal role of exchange currents in the traditional nuclear physics domain. And the second conclusion is that the high- q^2 results illustrate the need for an explicit inclusion of the sub-nucleonic hadronic degrees of freedom, or for QHD. And still another moral is the following: the appropriate set of degrees of freedom depends on the distance scale at which we probe the system. There is still a fourth moral. In order to make an unambiguous identification of the role of exchange currents, we had to have a theoretical calculation in which we believed, and it had to break down significantly in some kinematic domain.

Where are we today in nuclear physics? What we do is to study properties of the nuclear system at existing accelerators such as Bates at MIT, Saclay, NIKHEF, and others, and we find we can accurately interpret that data in terms of nucleonic and sub-nucleonic hadronic degrees of freedom. On the other hand, we have dynamic evidence for a pointlike substructure in the hadrons coming from the deep inelastic scattering experiments which were pioneered at SLAC [11] (deep inelastic scattering means that the energy loss in the lab gets very large, the four momentum transfer gets very large, but their ratio is fixed). Therefore, there is interesting, important physics in the intermediate range of energy loss and momentum transfer. And in fact, I would like to give you a quotation from the Vogt Subcommittee of NSAC, which was the last national committee in the United States to re-examine the top priority given to the construction of a 4 GeV CW electron linac in the United States. This committee concluded that:

"The search for new nuclear degrees of freedom and the relationship of nucleon-meson degrees of freedom to quark-gluon degrees of freedom in nuclei is one of the most challenging and fundamental questions of physics."

So what does the nucleus look like in the standard model? Figure 5 is a cartoon, but underneath that cartoon there is a lagrangian, and there are local currents. The currents and lagrangian are those of the standard model. The nucleus consists of a collection of baryons which are confined quark systems, confined presumably by the nonlinear gluon interaction. We know there are mesons present in the nuclear system; we have just seen evidence for that. The first observation is that the structure of confinement in the many-baryon system, as well as in the single-baryon system, is still an unsolved problem. And what nuclear physics does is to give us a way of varying the environment in which these hadrons find themselves.

Now suppose we interact with this system with an electroweak probe. This could be an electron or a neutrino interacting through the exchange of a photon, or a Z^0 , or a charged W . The electroweak interactions couple directly to the quarks in the standard model. The gluons are absolutely neutral. I like to think of it as a crystal ball inside of which you have tiny colored objects. And if you scatter light from the system, it goes right through the confining crystal ball. And that, in a certain sense, is an analog of what the nuclear system looks like. The electroweak interactions are colorblind. It does matter what color quark they end up on. Furthermore, one strikes a quark, but the quarks do not appear as the asymptotic scattering states in the laboratory; it is the hadrons that come out of the system. Hadronization is also an open problem.

Now simply given that picture of the nucleus, I would like to show you two really remarkable consequences [1, 12]. Let me simplify my discussion, if Jerry will let me, to the nuclear domain. In the nuclear domain I have only up (u) and down (d) quarks and any of number of \bar{u} and \bar{d} anti-quarks. Let me consider just that portion of the Hilbert space in the standard model consisting of only u and d quarks and their antiparticles. Furthermore, let me use the nucleus as an isospin filter. Suppose I go from a $T=0$ state to a $T=0$ state. In that case, the weak neutral current is exactly proportional to

the electromagnetic current. And that means the cross sections are proportional. For example, the cross section for neutrino scattering is proportional, through a known factor of proportionality, to the electron scattering cross section.

$$\frac{d\sigma_{\nu, \nu'}}{d\Omega} = \sin^4 \theta \frac{G^2 q^4}{2\pi^2 a^2} \frac{d\sigma_{e, e'}}{d\Omega} ; T = 0 \rightarrow T = 0$$

Now this really is a remarkable result. Because, this is a result that holds all q^2 , and hence, at all distance scales. It holds at low momentum transfers or large distance scales where we see only the gross properties of the nuclear system, out to higher momentum transfers or shorter distance scales where we see the granularity of the nuclear system in terms of neutrons and protons, out to higher momentum transfers or shorter distance scales where we see the mesonic or the sub-nucleonic hadronic degrees of freedom, and down to distance scales where we see the pointlike quark substructure of the system itself.

Let me put it more dramatically for you. If I could measure the elastic neutrino cross section for ^{40}Ca , and I divided out that known factor of proportionality, I should be able to lay the resulting diffraction pattern on top of the calcium diffraction pattern I showed you in Figure 1, and they should be identical over thirteen decades! There is a catch. It is not easy to measure neutrino cross sections. So let consider something else that we can measure.

In addition to the exchange of a photon in electron scattering, there is the exchange of a neutral Z^0 . At low and intermediate energies the effect of this term is completely masked because it is a weak interaction effect. It is masked unless I look at an effect that depends on the presence of the weak interactions. Parity violation is such an effect. So let me compute parity violation. One measure of parity violation is the difference in cross section for right and left-handed polarized electrons. Let me assume a V-A theory and let me assume that I am looking at a $0^+ \rightarrow 0^+$ nuclear transition. In that case you can calculate this parity violating asymmetry.

$$\begin{aligned} \mathcal{A}_{ee'} &= \frac{d\sigma_{\uparrow} - d\sigma_{\downarrow}}{d\sigma_{\uparrow} + d\sigma_{\downarrow}} \\ &= \frac{-q^2 G}{2\pi a \sqrt{2}} \left[\frac{F^{(0)}(q^2)}{F_{\gamma}(q^2)} \right] ; 0^+ \rightarrow 0^+ \end{aligned}$$

The asymmetry is again a known factor times the ratio of two form factors. The first one measures the distribution of weak neutral charge over the

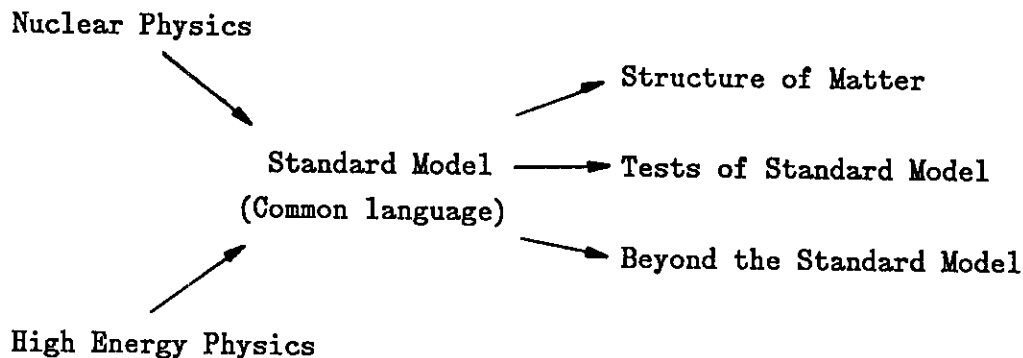
nuclear system, and the second is our old friend the electromagnetic form factor - it measures the distribution of electromagnetic charge over the nuclear system. Now let us go to the standard model, and let us suppose again that the nucleus has isospin 0 - for example, our old friend ^{40}Ca . In that case, the weak neutral current and the electromagnetic current are exactly proportional and this form factor ratio is a constant at all q^2 . In fact, the expression for the asymmetry, which was first derived by Feinberg [13], is:

$$A_{ee'} = \frac{q^2 G}{\pi \alpha \sqrt{2}} \sin^2 \theta_w \quad ; \quad \begin{array}{l} 0^+ \rightarrow 0^+ \\ T=0 \rightarrow T=0 \end{array}$$

Again, everything I have said before about the neutrino cross sections also holds here. The fact that this form factor ratio is strictly a constant at all q^2 , to me, is a true test of the unification of the electroweak interactions.

Let me set up a straw man for you. The straw man says, "We have quarks and gluons and the lagrangian of QCD, and therefore the problem is no longer interesting." I bet you have never heard anything like that. Let me make the same comment. "We have electrons and we have protons (in nuclei), and the lagrangian of QED." Well, what are the consequences? We have atoms. Then we have crystals. Then we have semiconductors and we have superconductors. Then we have superfluids. Then atoms can form molecules and we have chemistry, we have biology, and we have life. This is not an uninteresting set of consequences following from that lagrangian and that underlying set of degrees of freedom.

Where are we? One of the things that pleases me is that nuclear physics and particle physics have really started to come together again.



And the reason for this coming together is really the standard model. The standard model gives us a common language. Now it is not a familiar language to a great many nuclear physicists, because it is the language of relativistic quantum field theory based on a local lagrangian density. But it is a language we have to learn, because this is indeed the underlying theory of the structure of matter. And now the aims diverge in my opinion. Nuclear physics is really the study of the structure of matter. What happens when we put this stuff together? High energy physics basically asks, what is there beyond the standard model? One tries to go to high-enough energies, or

short-enough distance scales, to see what is beyond the standard model. And of course, all of us are interested in formulating detailed precision tests of this standard model.

The field of electromagnetic studies of nuclear structure has been successful, through the work done, for example, at the laboratories that I mentioned before. And success generates opportunities. In fact NSAC, the Nuclear Science Advisory Committee, has recommended a forefront balanced program of electromagnetic studies of nuclei as one of the top priorities for the future direction of nuclear physics in the United States. Illinois has a proposal for a 450 MeV microtron, Bates has a proposal for a pulse stretcher ring operating at 1 GeV, and CEBAF, a 100% duty factor linac operating at 4 GeV and above, is an approved project. It is my expectation that, in fact, all of these projects will get funded in the United States. High energy physics has SLAC and its NPAS program and the Stanford Linear Collider (SLC) which is an e^+e^- linear collider operating at approximately 100 GeV. My strongest argument for approving the proposals for Illinois and Bates is that they are the primary source of young people for the field in the United States, and in fact for all of nuclear science. And bright creative young people are not only essential to the science, but are the most valuable resource we have.

So if the Chairman will give me five minutes, (. . four and a half ? . .), I will spend four and a half minutes talking about CEBAF.

I have tried to crystallize my own thoughts on CEBAF. CEBAF will provide the most precise accessible probe of matter. The interaction is known, one knows what is being measured. It is a unique time for nuclear physics. What we are really discussing is a tool and a capability for the next generation of nuclear scientists.

To me, CEBAF's scientific goal is to study the structure of the nuclear many-body system, its quark substructure, and the strong and electroweak interactions governing the behavior of this fundamental form of matter.

Christoph Leemann told you about the CEBAF project this morning. We have appointed a Program Advisory Committee to give us guidance on the scientific program, (I give you the membership in Figure 6). The first meeting was held in February and the Committee has provided us guidance on the program. The way we proceeded was to set up a set of Steering Committees coming from the national users community. These were the natural outgrowth of the workshops and summer study programs that had been held over the past several years. The Steering Committees were centered on the possible experimental programs that can be carried out at CEBAF. These are listed in Figure 7. CEBAF gives you a continuous beam. It allows you to do coincidence experiments where you can look at the hadron produced in coincidence with the scattered electron, and study the process of hadronization. Listed are simply the particles you can detect in coincidence: (e, e' nucleon); ($e, e' K^+$) and ($e, e' \pi$), the first of which gives you a tagged hyperon, and, in fact, with good resolution you can do precise hypernuclear spectroscopy; (e, e' two nucleon) where hopefully, one can get at the short-range correlation of two nucleons, or at multiquark clustering, in the nuclear system. There is the parity-violation experiment. We are going to have polarized beam. We are going to do that experiment. The PAC said our top priority should be the few-nucleon systems - to both look at the wave functions for the few-nucleon systems and also to try and extract the form

factors of the nucleons. We will study the properties of the isobars that Ernie Moniz talked about this morning through $N(e,e')N^*$. And we will hopefully push the kinematic regime in all these experiments out to asymptopia, or at least asymptopia as seen at SLAC in the deep-inelastic scattering experiments.

Our own institutional goal at CEBAF is to build a world-class user friendly laboratory for nuclear physics research and graduate education, centered around a high-intensity 4 GeV CW electron accelerator.

I would like to close with three quotations, just to give you some food for thought. I like these quotations and I use them all the time. The first one is a question that Herb Anderson asked after a talk Herman Feshbach gave at a LAMPF II workshop (this is now the Advanced Hadron Facility we just heard about). He asked:

"We have been doing nuclear physics for 50 years without quarks, why do we need them now?" (H. Anderson, LAMPF II Workshop, 1983)

This is actually a very profound question for nuclear physics and nuclear physicists. I urge you to think about it very carefully.

The second quotation is a comment Bob Wilson made to me in a private discussion. He said:

"The single most important practical application of the recent advances in particle physics may well be the revolution in our picture of the nucleus." (R.R. Wilson, private communication, 1984)

And finally, there is a new definition of the field of nuclear physics, given by Nathan Isgur at a CEBAF workshop, that is really appropriate for the next decade:

"Nuclear physics is the study of the strong- interaction, confinement aspects of QCD." (N. Isgur, CEBAF Summer Workshop, 1984)

References

- [1] J. D. Walecka, "Electron Scattering," ANL-83-50, Argonne Nat. Lab. (1984)
- [2] B. Frois et al., Lect. Notes in Phys. 108, Springer (1979), p. 52
- [3] A. L. Fetter and J. D. Walecka, Quantum Theory of Many-Particle Systems, McGraw-Hill, New York (1971)
- [4] B. D. Serot and J. D. Walecka, "The Relativistic Nuclear Many-Body Problem," Adv. in Nucl. Phys., Vol. 16, eds. J. W. Negele and E. Vogt, Plenum Press, New York (1986)

- [5] S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967); Phys. Rev. D5, 1412 (1972)
- [6] A. Salam and J. C. Ward, Phys. Lett. 13, 168 (1964)
- [7] S. L. Glashow et al., Phys. Rev. D2, 1285 (1970)
- [8] F. Wilczek, Ann. Rev. of Nucl. Sci. 32, 177 (1982)
- [9] J. Dubach et al., Nucl. Phys. A271, 279 (1976)
- [10] J. M. Cavedon et al., Phys. Rev. Lett. 49, 986 (1982)
- [11] J. I. Friedman and H. W. Kendall, Ann. Rev. Nucl. Sci. 22, 203 (1972)
- [12] J. D. Walecka, A.I.P. Conf. Proc. 123, A.I.P., New York (1984), p. 1-14
- [13] G. Feinberg, Phys. Rev. D12, 3575 (1975)

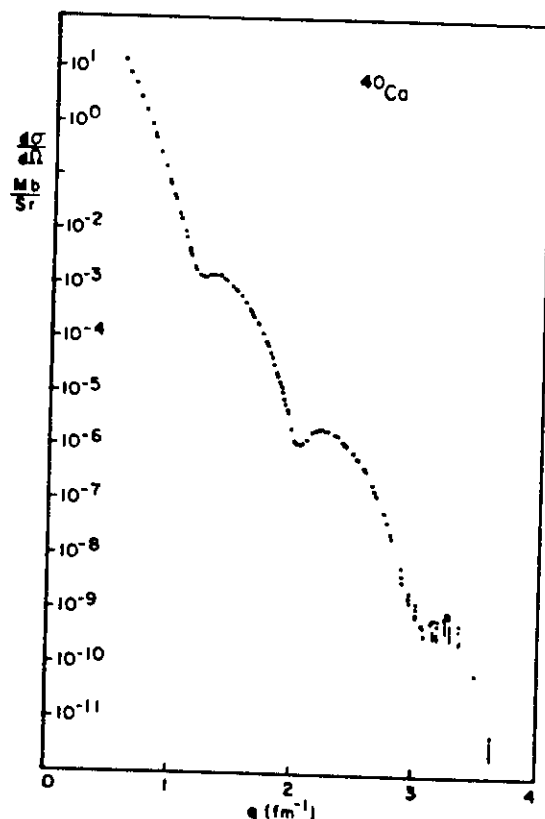


Fig. 1 Elastic (e,e) cross section for ^{40}Ca vs. momentum transfer [2]. The scattering here is from the charge distribution.

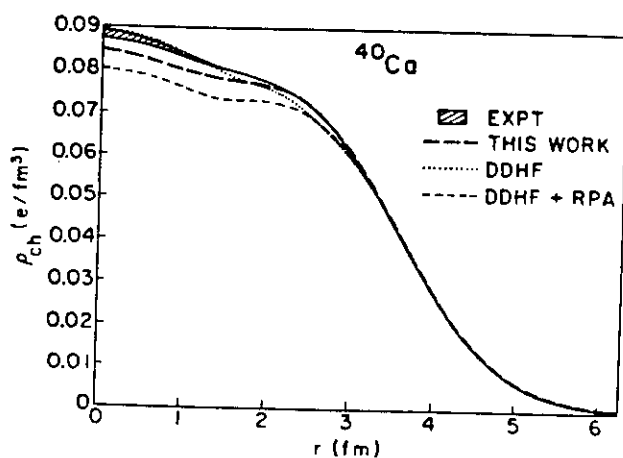


Fig. 2 Experimental charge density of ^{40}Ca with estimated uncertainty from elastic electron scattering (solid lines and shaded area) and relativistic Hartree calculations of this quantity within the framework of QHD (heavy dashed line). Taken from refs. [2, 4].

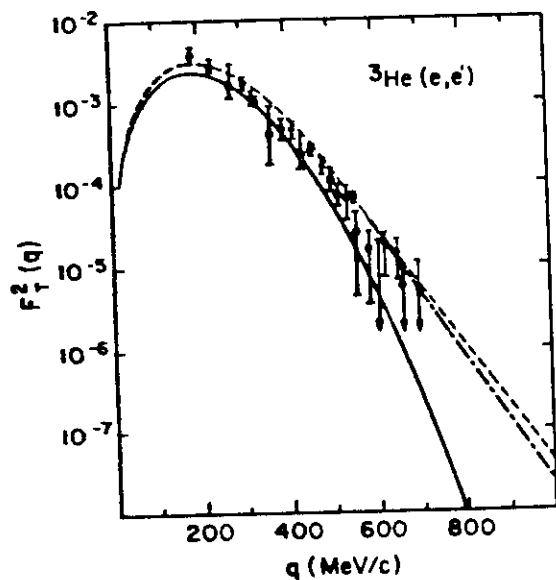


Fig. 3 Elastic transverse form factor for ${}^3\text{He}$ (e,e') with (dashed) and without (solid) one-pion-exchange currents [9].

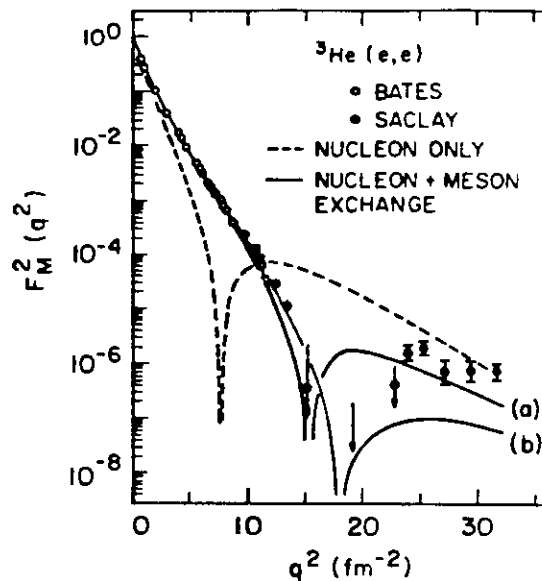


Fig. 4 Elastic magnetic form factor for ${}^3\text{He}$ (e,e) out to high q^2 [10]. Two exchange current theories are shown.

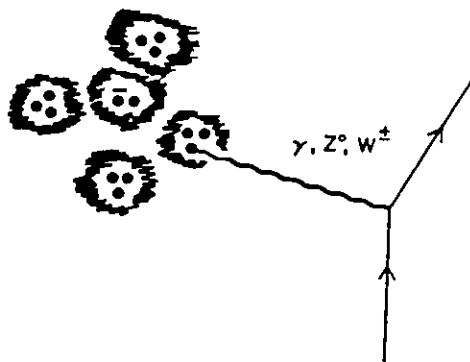


Fig. 5 Picture of the nucleus in the Standard Model.

**PROGRAM ADVISORY
COMMITTEE (PAC) CEBAF**

o **Function**

Advise CEBAF Directorate on
scientific directions and relative
scientific priorities for the
experimental program

o **Membership**

J. Schiffer (Argonne), Chairman
P. Barnes (Carnegie-Mellon)
W. Bertozzi (MIT)
T. W. Donnelly (MIT)
R. Eisenstein (Illinois)
J. Friar (LANL)
S. Kowalski (MIT)
R. McKeown (Caltech)
E. Moniz (MIT)
I. Sick (Basel)
H. Thiessen (LANL)
C. Williamson (MIT)
S. Wojcicki (Stanford)

o **First Meeting**

February 13-15, 1987

o **Report completed**

Figure 6

**SUBJECT AREAS FOR
STEERING COMMITTEES CEBAF**

- o (e,e' nucleon)
- o (e,e'K) and (e,e'π)
- o (e,e' two nucleon)
- o (e,e' multihadron)
- o p(ē,e)p parity
- o few nucleon systems
- o (e,e'N*)
- o (e,e'X) deep inelastic transition to X
scaling

Figure 7